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Iida et al.

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(54) **ILLUMINATION DEVICE AND REFLECTION CHARACTERISTIC MEASURING DEVICE**

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G01J 3/50	(2006.01)
G01J 1/42	(2006.01)
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(52) **U.S. Cl.**

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(58) **Field of Classification Search**

CPC G01J 3/02; G01J 3/42; G01J 3/28; G01N 21/31; G01N 21/552

USPC 356/300–445

See application file for complete search history.

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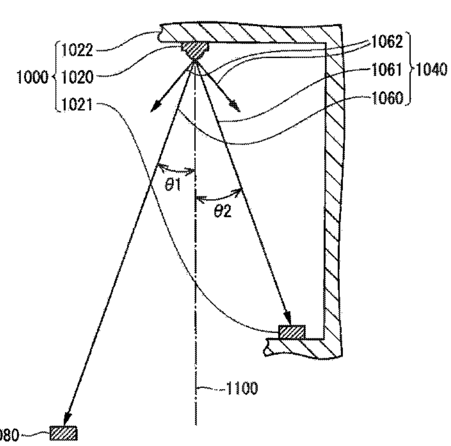
(57) **ABSTRACT**

An illumination device is provided with a light source, a photodetector, and a support structure. The light source, which emits light, has light distribution in which a reference axis serves as an axis of symmetry or light distribution in which a plane including the reference axis serves as a plane of symmetry. A first light beam in the light is guided to the object to be illuminated. A second light beam in the light is guided to the photodetector. The photodetector detects intensity of the second light beam. The light source and the photodetector are supported by the support structure in positions and postures that allow the first light beam and the second light beam to be guided in an aforementioned manner. A traveling direction of the first light beam and a traveling direction of the second light beam make the same angle with the reference axis.

14 Claims, 13 Drawing Sheets



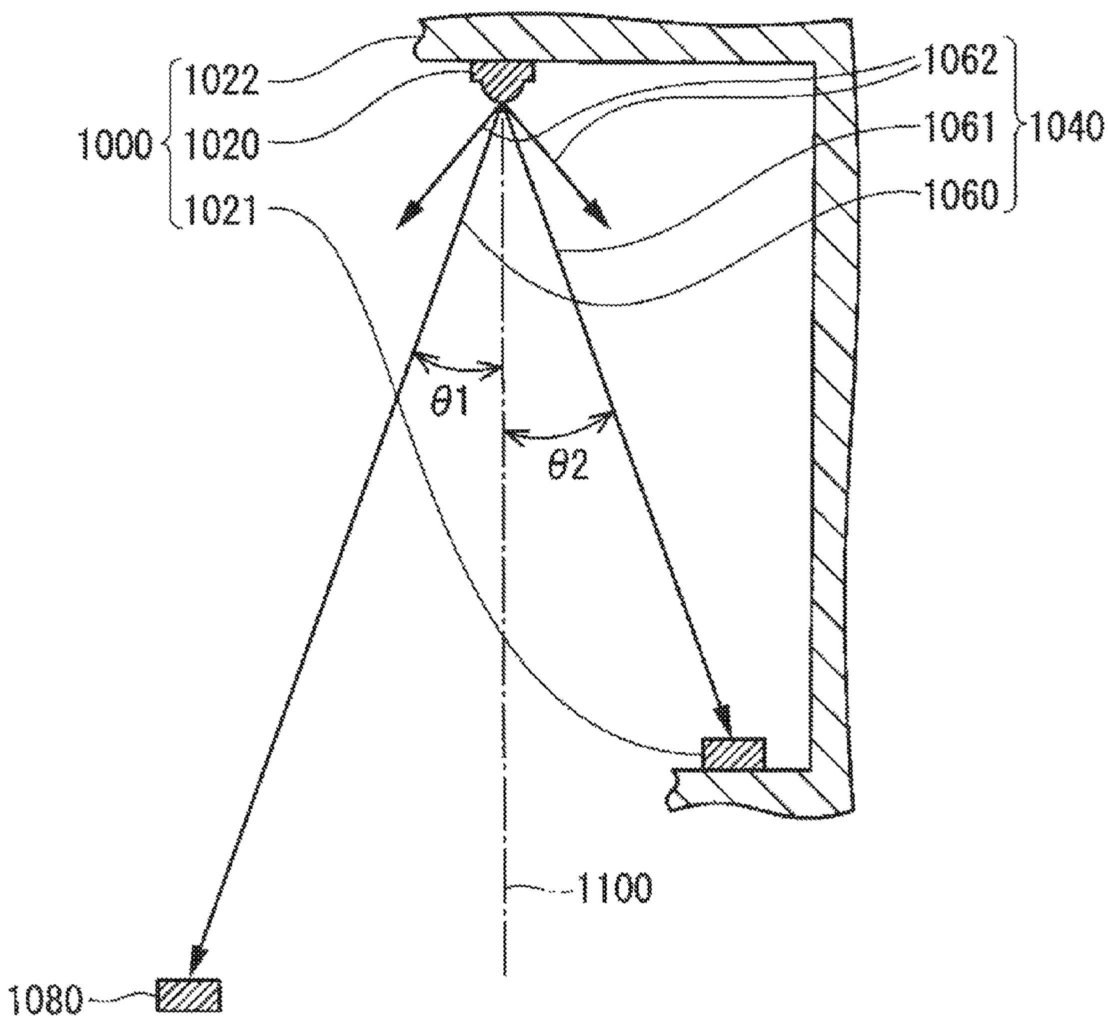

1022
1000
1020
1021
1062
1061
1040
1060
θ1
θ2
1100
1080

FIG. 2

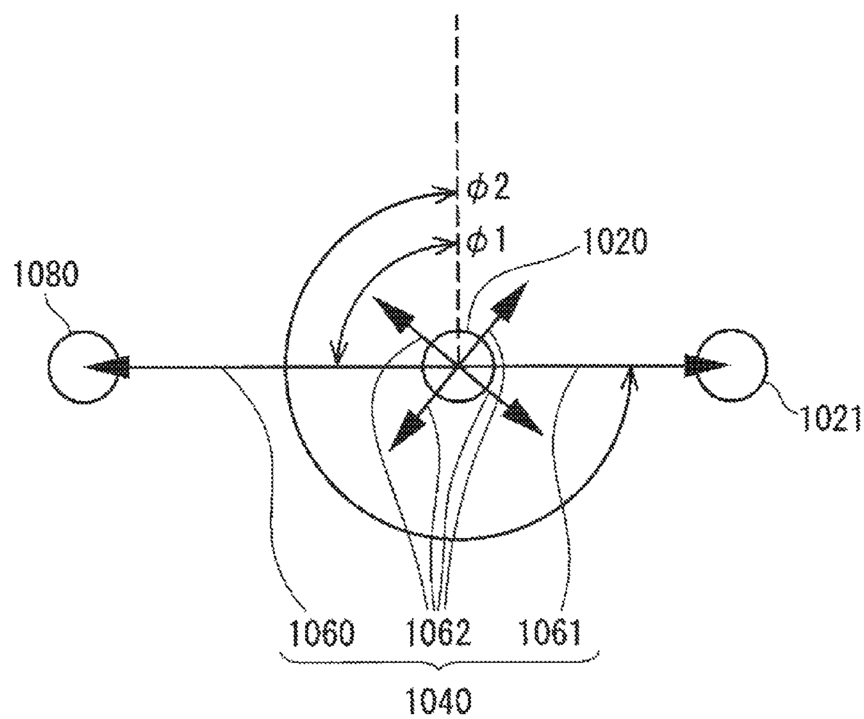

φ2
φ1
1020
1080
1021
1060
1062
1061
1040

FIG. 3

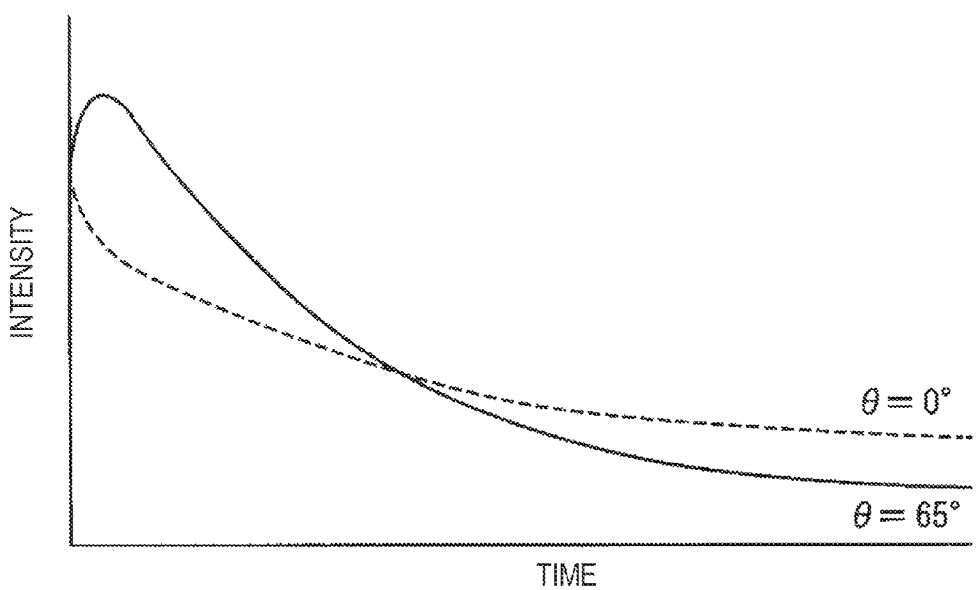

INTENSITY
θ = 0°
θ = 65°
TIME

FIG. 4

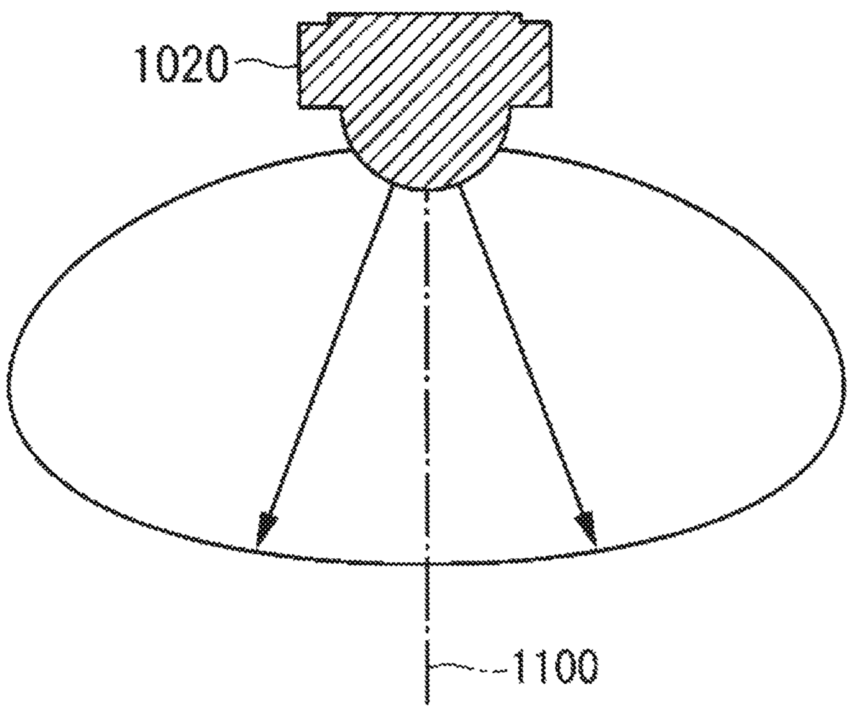


FIG. 5

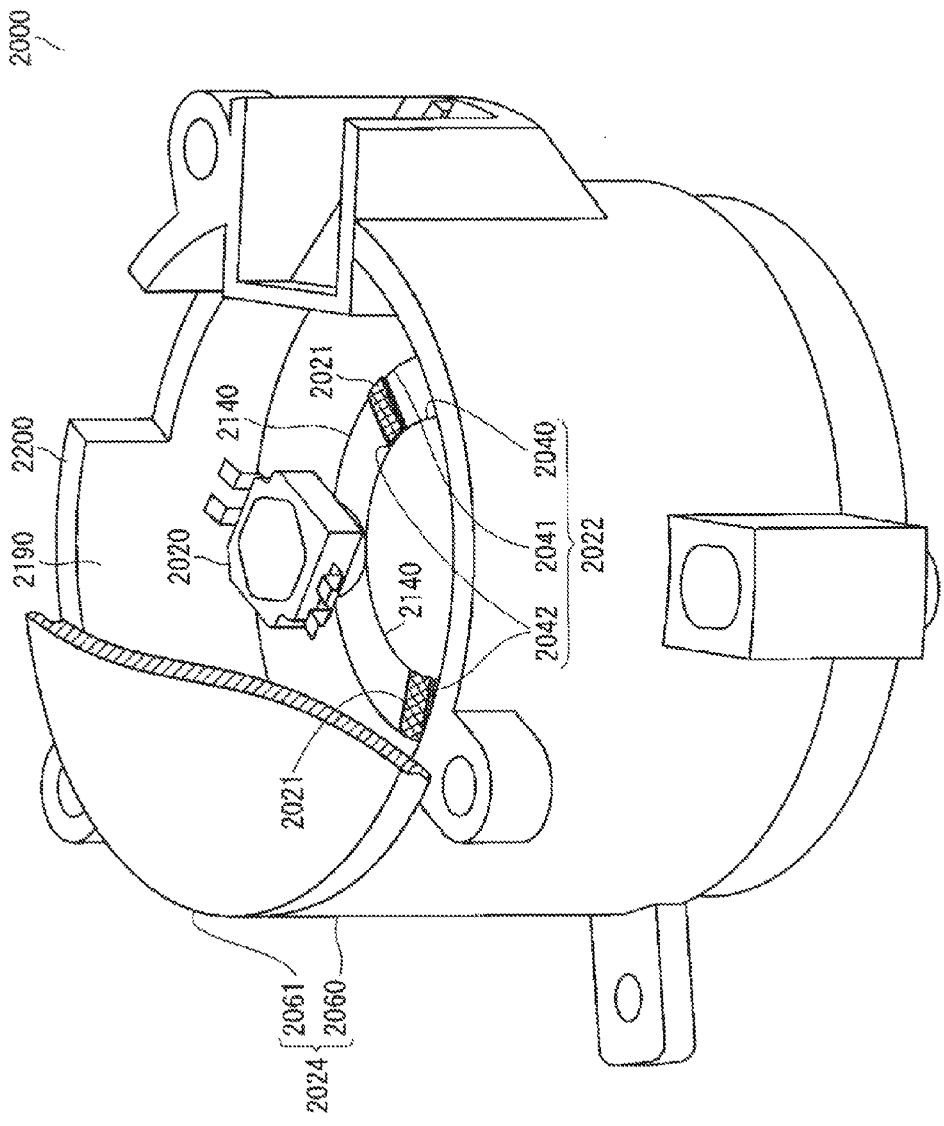

2000
2200
2190
2020
2140
2021
2040
2041
2022
2042
2140
2021
2061
2060
2024

FIG. 6

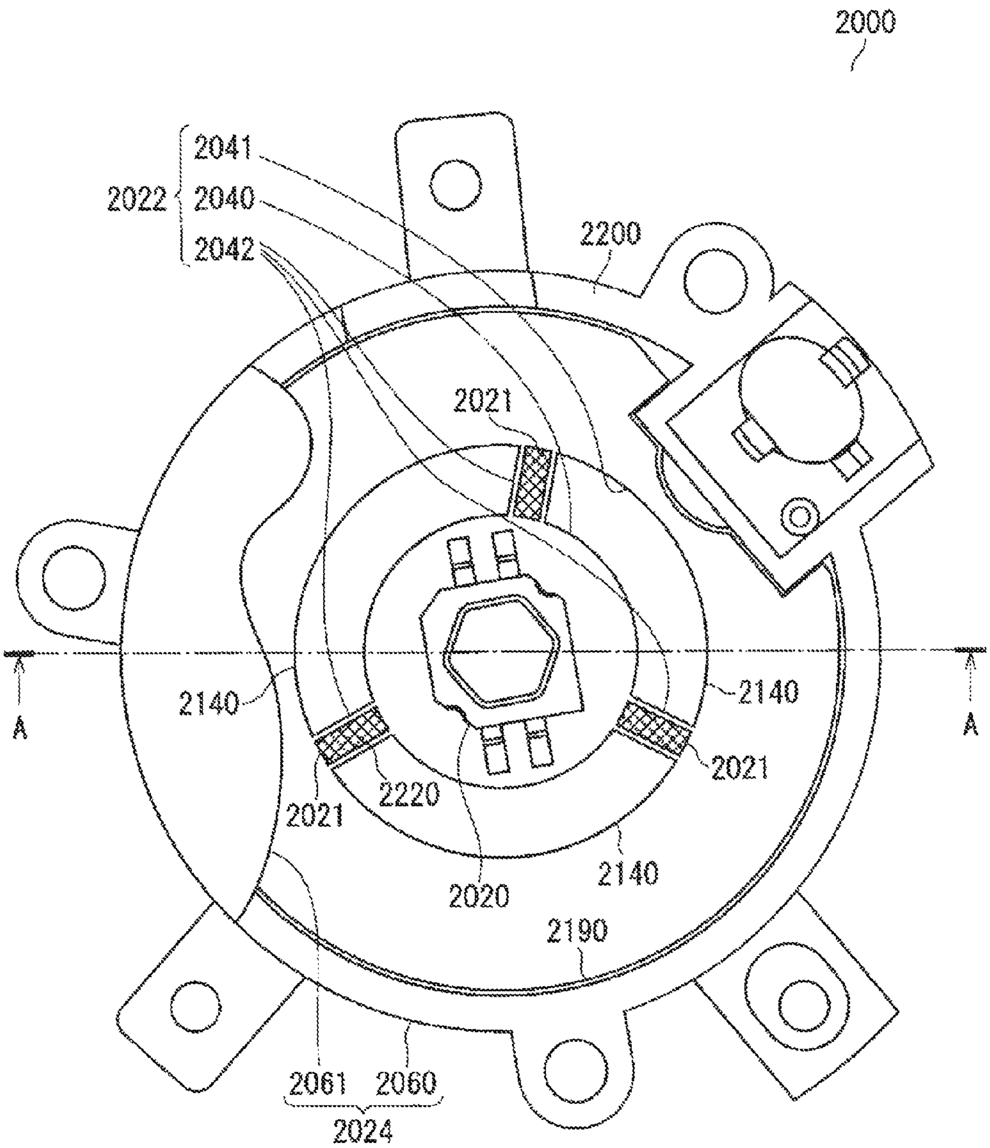

2000
2022
2041
2040
2042
2200
2021
2140
2140
A
A
2021
2021
2220
2140
2020
2190
2061
2060
2024

FIG. 7

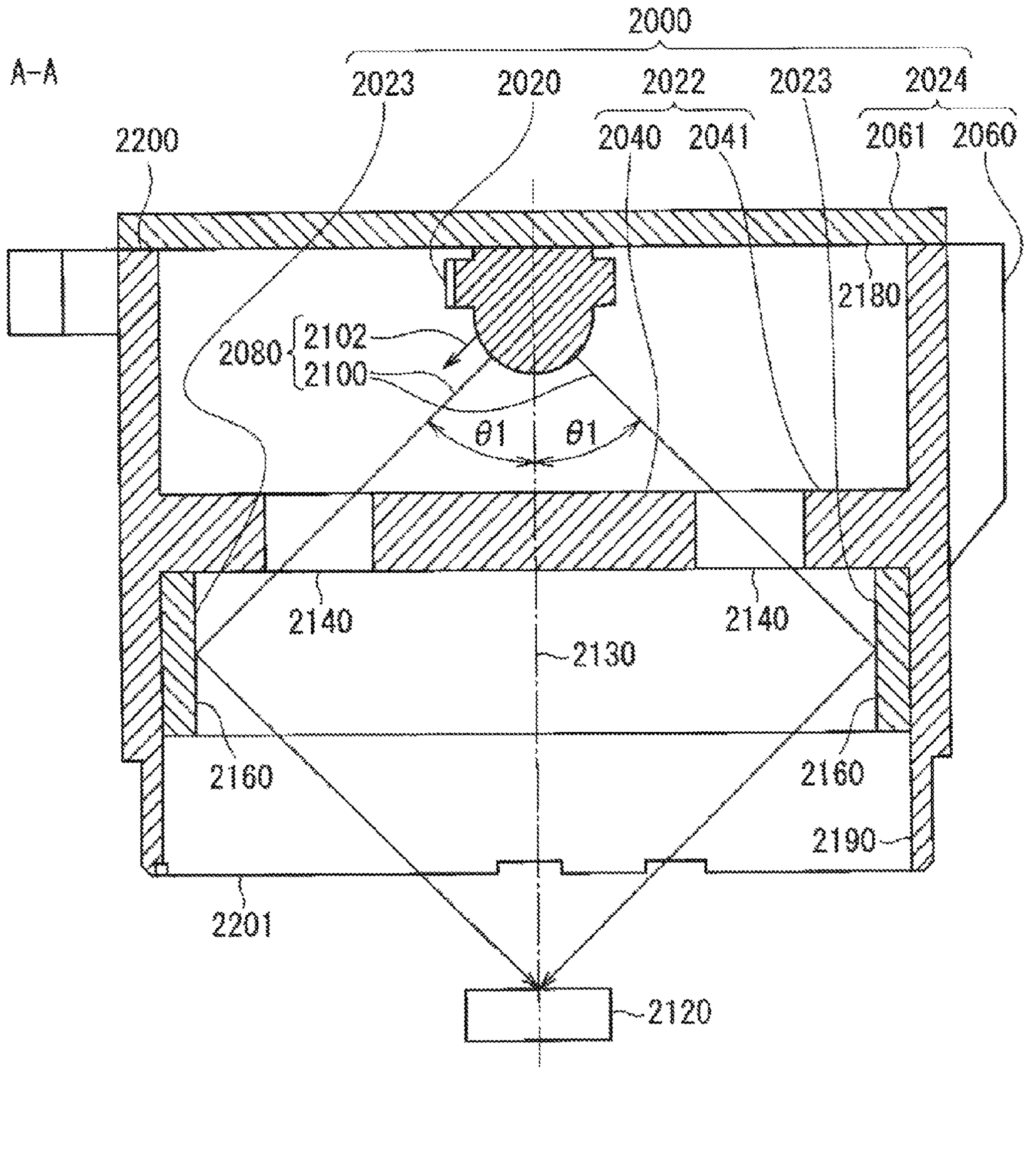
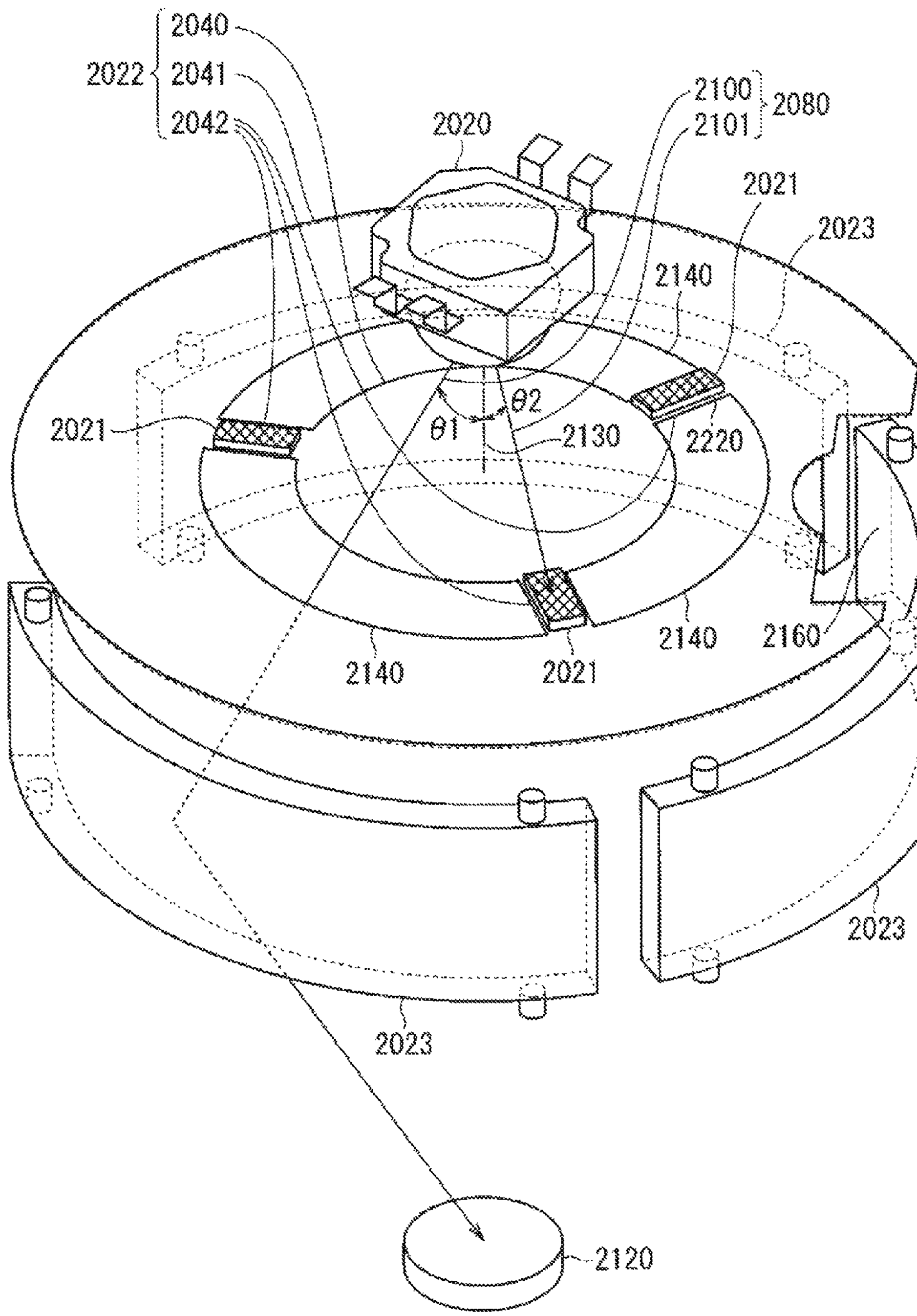

A-A
2000
2023
2020
2022
2023
2024
2040
2041
2061
2060
2200
2180
2080
2102
2100
θ1
θ1
2140
2140
2130
2160
2160
2190
2201
2120

FIG. 8



2022
2040
2041
2042
2020
2100
2101
2080
2021
2023
2140
2021
2220
θ2
θ1
2130
2160
2140
2140
2021
2023
2023
2120

FIG. 9

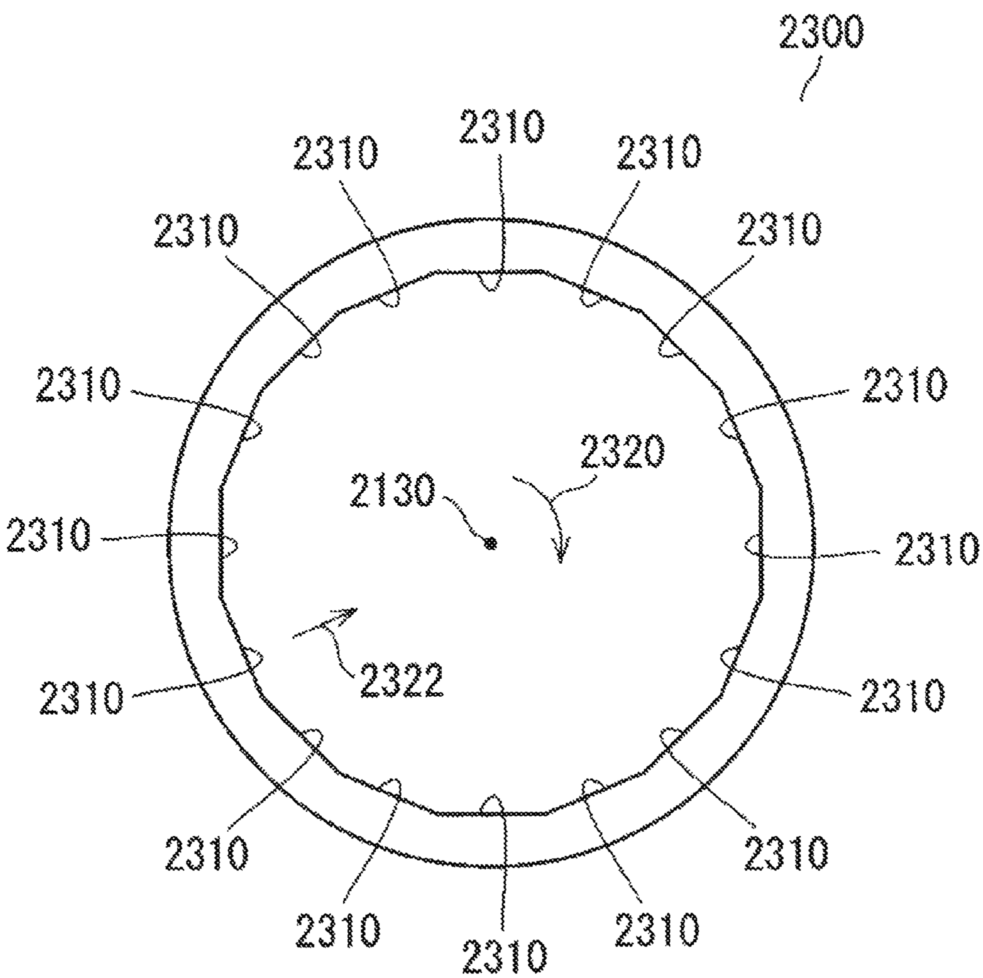


FIG. 10

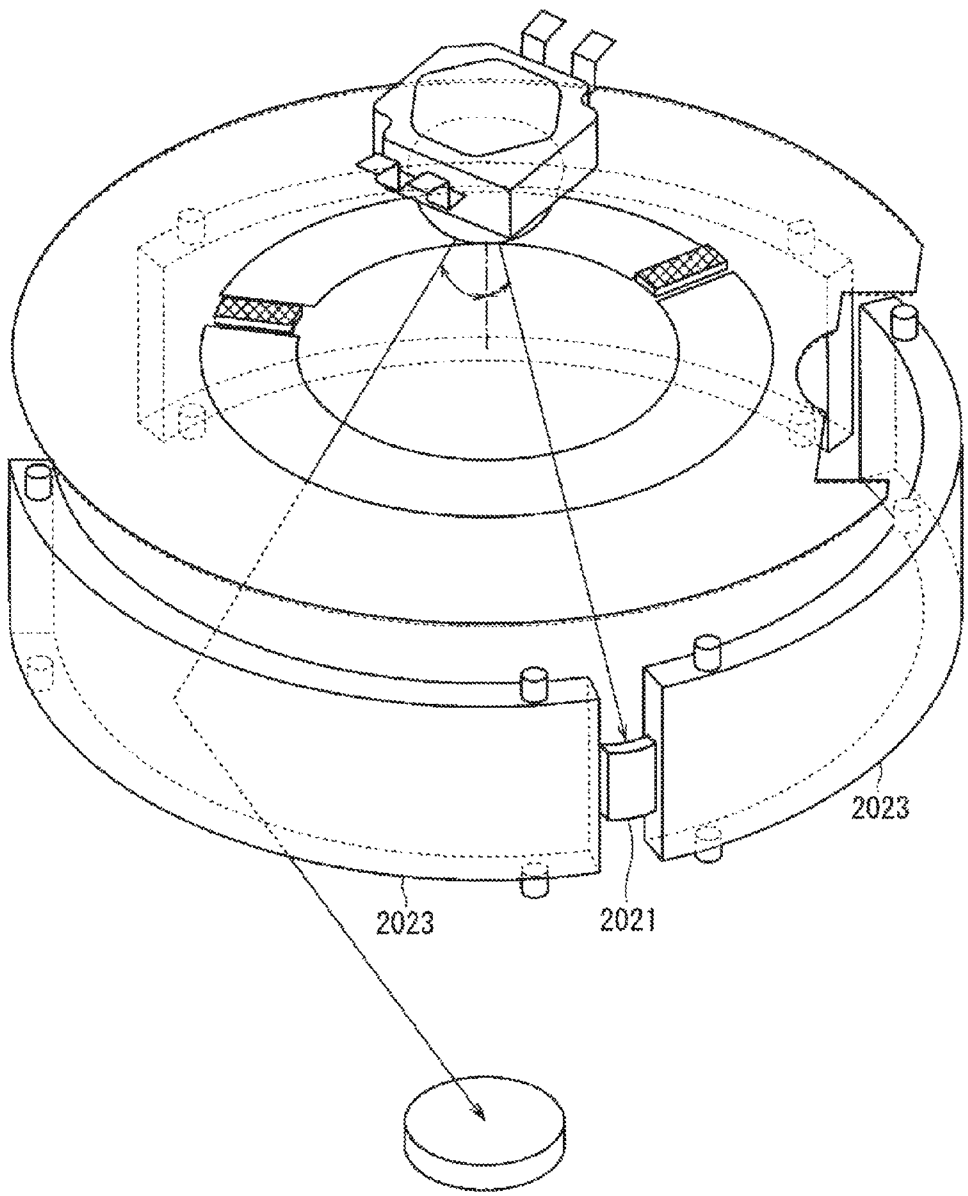


FIG. 11

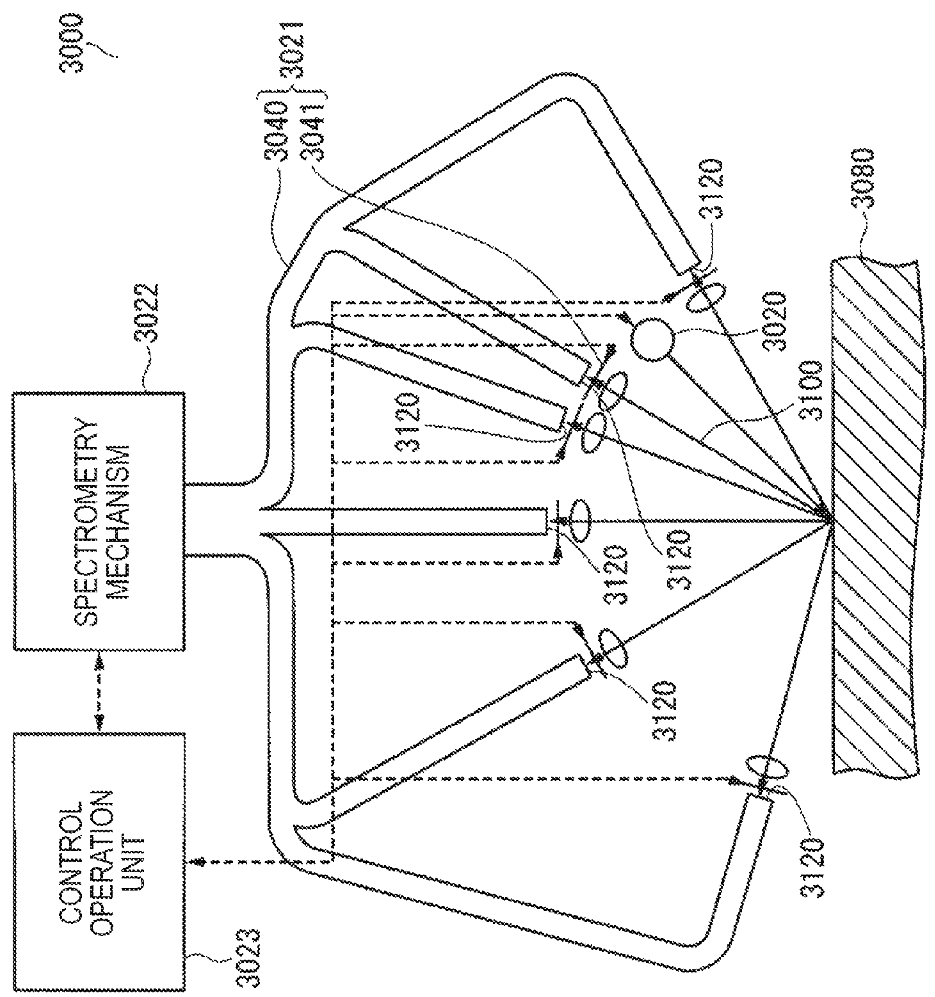

3000
3040
3041
3021
3022
SPECTROMETRY MECHANISM
CONTROL OPERATION UNIT
3023
3020
3100
3120
3120
3120
3120
3120
3120
3080

FIG. 12

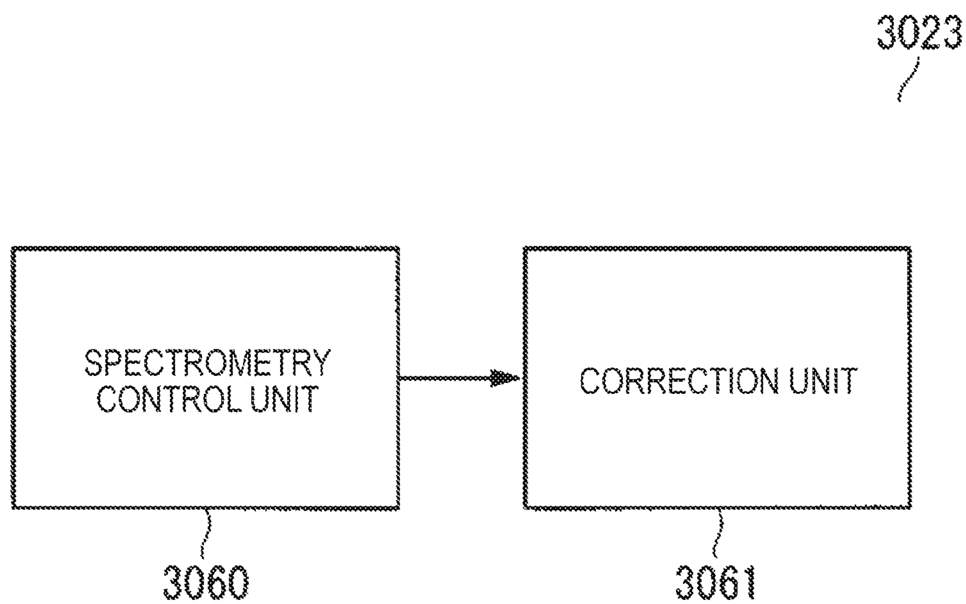


FIG. 13

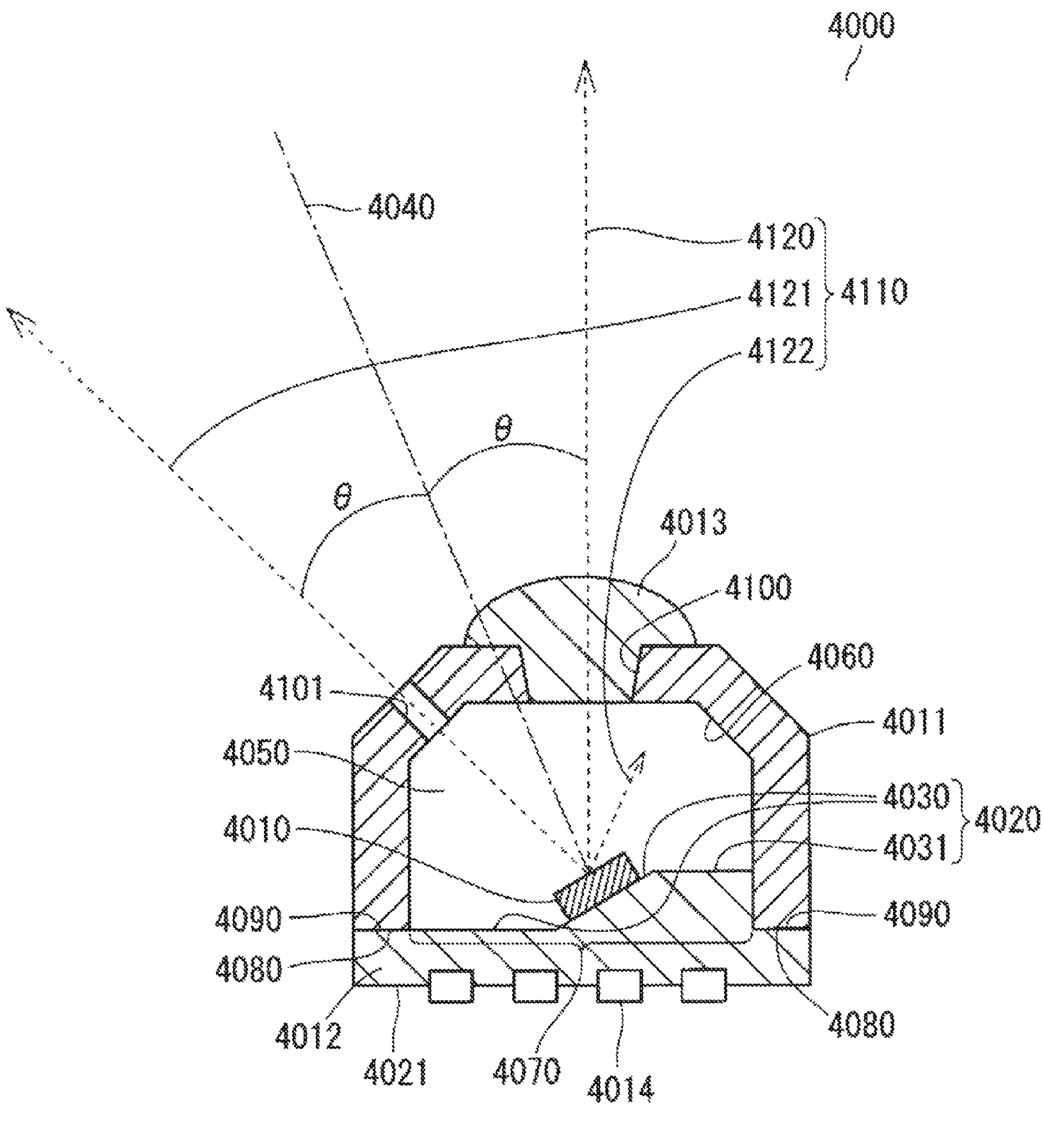

4000
4040
4120
4121
4110
4122
θ
θ
4013
4100
4060
4101
4011
4050
4030
4020
4010
4031
4090
4090
4080
4080
4012
4021
4070
4014

FIG. 14

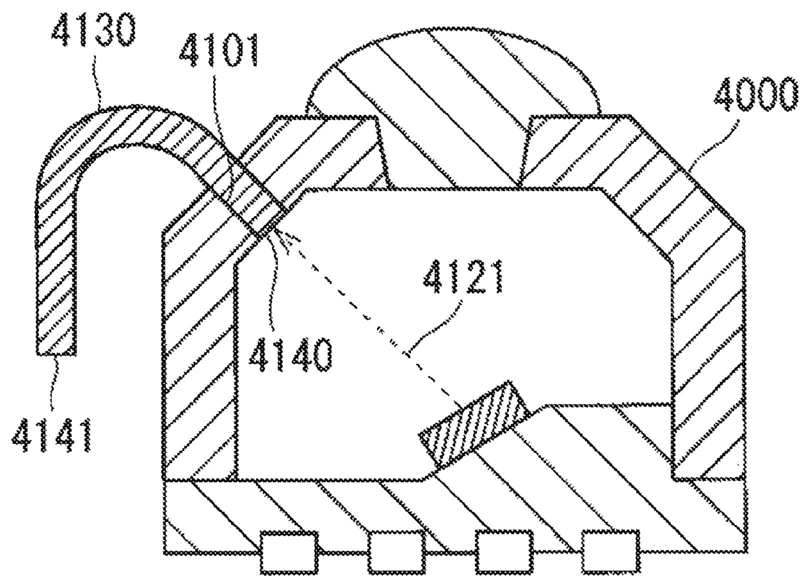
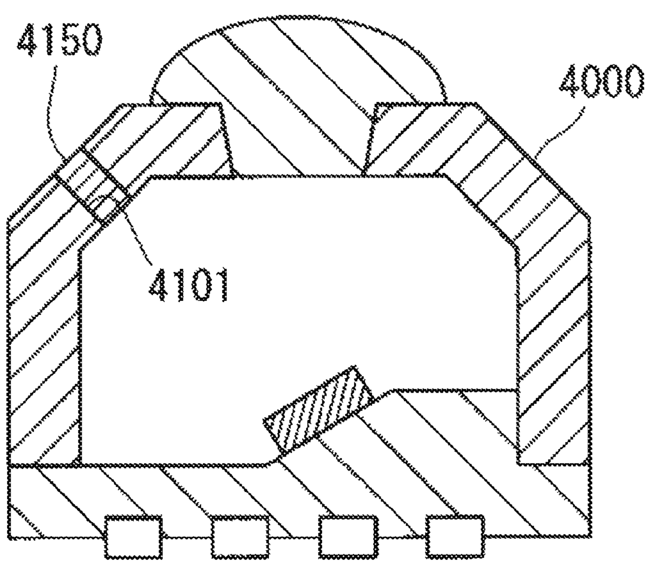


FIG. 15



ILLUMINATION DEVICE AND REFLECTION CHARACTERISTIC MEASURING DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a national stage of international application no. PCT/JP2014/062962, filed May 15, 2014, which claims the benefit of Japanese application number 2013-112846, filed May 29, 2013, the disclosures of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present invention relates to an illumination device and a reflection characteristic measuring device.

BACKGROUND ART

Measurement results of measuring devices that illuminate samples, and measure reflection light, transmitted light, and the like from the samples are affected by intensity of illumination light. Therefore, it is required to monitor the intensity of the illumination light in the measuring devices.

For example, in the technology of Patent Literature 1, a light beam emitted from a light source (LED) in a normal line direction is guided to the sample, and becomes the illumination light, and a light beam emitted from the light source in a non-normal line is guided to a photodetector (light-receiving sensor). The intensity of the light beam guided to the photodetector is detected by the photodetector. A detection result of the photodetector is used for correction of a measurement result.

CITATION LIST

Patent Literature

Patent Literature 1: JP 2002-214126 A

SUMMARY OF INVENTION

Technical Problem

However, in the technology of Patent Literature 1, the intensity of the light beam guided to the photodetector may not be temporally changed similarly to the intensity of the light beam guided to the sample, and the detection result of the photodetector may not serve as an index that appropriately reflects the intensity of the light beam guided to the sample. In such a case, the measurement result is not appropriately corrected.

The present invention is made to solve the problem. An object of the present invention is to provide an illumination device form which an index that appropriately reflect the intensity of a light beam guided to an object to be illuminated can be obtained. Further, an object of the present invention is to provide a reflection characteristic measuring device that correctly performs spectrometry.

Solution to Problem

According to a desirable form, an illumination device includes a light source, a photodetector, and a support structure. The light source emits light. The light source has light distribution in which a reference axis serves as an axis of symmetry or light distribution in which a plane including a reference axis serves as a plane of symmetry. A first light beam included in the light is guided to an object to be illuminated. A second light beam included in the light is guided to the photodetector. The photodetector detects intensity of the second light beam. The light source and the photodetector are supported by the support structure in positions and postures that allow the first light beam and the second light beam to be guided in an aforementioned manner. A traveling direction of the first light beam makes a first angle with the reference axis. A traveling direction of the second light beam makes a second angle with the reference axis. The second angle is the same as the first angle.

According to a desirable form, a reflection characteristic measuring device includes the above-described illumination device, a spectrometry mechanism, and a correction unit. The spectrometry device performs spectrometry of reflection light from an object to be illuminated. A correction unit corrects a measurement result of the spectrometry mechanism, using a detection result of the photodetector. In this correction, correction to resolve temporal change of the intensity of the first light beam is performed.

The objects, characteristics, aspects, and advantages of the invention, and objects, characteristics, aspects, and advantages other than the aforementioned points of the present invention will become apparent by detailed description of the present invention below when considered together with the appended drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a sectional view of an illumination device of a first embodiment.

FIG. **2** is a top view of an arrangement of a light-emitting diode and the like in the first embodiment.

FIG. **3** is a graph illustrating temporal change of intensity of light beams.

FIG. **4** is a sectional view illustrating light distribution of a light-emitting diode.

FIG. **5** is a perspective view of an illumination device of a second embodiment.

FIG. **6** is a top view of the illumination device of the second embodiment.

FIG. **7** is a sectional view of the illumination device of the second embodiment.

FIG. **8** is a perspective view illustrating an arrangement of a light-emitting diode and the like in the second embodiment.

FIG. **9** is a top view of a polyhedral mirror.

FIG. **10** is a perspective view of another arrangement of the light-emitting diode and the like in the second embodiment.

FIG. **11** is a block diagram of a multiangle colorimeter.

FIG. **12** is a block diagram of a control operation unit.

FIG. **13** is a sectional view of a light-emitting diode unit of a fourth embodiment.

FIG. **14** is a sectional view of the light-emitting diode unit and the like of the fourth embodiment.

FIG. **15** is a sectional view of the light-emitting diode and the like of the fourth embodiment.

DESCRIPTION OF EMBODIMENTS

First Embodiment

A first embodiment relates to an illumination device.

The sectional view of FIG. **1** schematically illustrates an illumination device **1000** of the first embodiment. The top view of FIG. **2** schematically illustrates an arrangement of a light-emitting diode **1020**, a photodiode **1021**, and an object to be illuminated **1080**.

As illustrated in FIGS. **1** and **2**, the illumination device **1000** includes the light-emitting diode **1020**, the photodiode **1021** and a support structure **1022**.

The light-emitting diode **1020** emits light **1040**.

The light **1040** is formed of a first light beam **1060**, a second light beam **1061**, and a residual light beam **1062**. The first light beam **1060** is directly guided to the object to be illuminated **1080**, and becomes illumination light. The second light beam **1061** is directly guided to the photodiode **1021**.

A zenith angle θ**2** in a traveling direction of the second light beam **1061** is the same as a zenith angle θ**1** of a traveling direction of the first light beam **1060**. An azimuth angle ϕ**2** of the traveling direction of the second light beam **1061** is different from an azimuth angle ϕ**1** of the traveling direction of the first light beam **1060**. The zenith angles θ**1** and θ**2** indicate angles made with a reference axis **1100**. The azimuth angles ϕ**1** and ϕ**2** indicate rotation angles around the reference axis **1100**.

A spread angle of the first light beam **1060** is set to be small both in a zenith angle direction and an azimuth angle direction, and is desirably set to 2° or less. When the spread angle of the first light beam **1060** is set to be small, variation of an incident angle of a plane to be illuminated of the object to be illuminated **1080** becomes small. Note that the spread angle of the first light beam **1060** may be set larger both or one of in the zenith angle direction and the azimuth angle direction. A spread angle of the second light beam **1061** is set to the same as the spread angle of the first light beam **1060** in the zenith angle direction. The spread angle of the second light beam **1061** may be set to be larger or smaller than the spread angle of the first light beam **1060** in the azimuth angle direction, or may be set to the same as the spread angle of the first light beam **1060**.

The light-emitting diode **1020** may be replaced with another type of light source. For example, the light-emitting diode **1020** may be replaced with a halogen lamp, Xenon lamp, or the like.

The photodiode **1021** detects intensity of the second light beam **1061**, and output an electrical signal according to the intensity of the second light beam **1061**.

The zenith angle θ**2** is the same as the zenith angle θ**1**. Therefore, the intensity of the second light beam **1061** is temporally changed similarly to intensity of the first light beam **1060**. From the photodiode **1021**, an index that appropriately reflects the intensity of the first light beam **1060** guided to the object to be illuminated **1080** can be obtained.

In contrast, when the zenith angle θ**2** is different from the zenith angle θ**1**, the intensity of the second light beam **1061** is not temporally changed similarly to the intensity of the first light beam **1060**. For example, the zenith angle θ**1** is 0° and the zenith angle θ**2** is 65°, while the intensity of the first light beam **1060** is monotonously decreased, the intensity of the second light beam **1061** is increased once then sharply decreased to become lower than the intensity of the first light beam **1060**, as illustrated in the graph of FIG. **3** that illustrates the temporal change o the intensity of the light beams. FIG. **3** illustrates the temporal change of the intensity of the light beams from when the light-emitting diode **1020** is lighted to when a time of about 0.1 seconds elapses.

The photodiode **1021** may be replaced with another type of photodetector. For example, the photodiode **1021** may be replaced with a photoresistor, a photomultiplier, or the like.

The first light beam **1060** is guided to the object to be illuminated **1080**, and becomes the illumination light. The second light beam **1061** is guided to the photodiode **1021**. The support structure **1022** supports the light-emitting diode **1020** and the photodiode **1021** in positions and postures that allow the first light beam **1060** and the second light beam **1061** to be guided in an aforementioned manner.

The illumination device **1000** may include a structure other than the aforementioned structures. For example, an optical system that converges, radiates, reflects, or refracts both or one of the first light beam **1060** and the second light beam **1061** may be provided. The optical system includes a lens, a prism, a mirror, an optical fiber, and the like. When the residual light beam **1062** becomes stray light and affects illumination to the object to be illuminated **1080** or detection of the intensity of the second light beam **1061** with the photodiode **1021**, a shield that shields the residual light beam **1062** is desirably provided.

The sectional view of FIG. **4** schematically illustrates light distribution of the light-emitting diode **1020**.

The light distribution of the light-emitting diode **1020** is axially symmetrical light distribution (rotationally symmetrical light distribution). The light distribution of the light-emitting diode **1020** may be symmetrical light distribution other than the axially symmetrical light distribution. For example, the light distribution of the light-emitting diode **1020** may be light distribution symmetrical about two planes, light distribution symmetrical about one plane, or the like.

The axially symmetrical light distribution is light distribution that can be expressed by rotation of a polar coordinate light distribution curve in a plane that includes an axis of rotation around the axis of rotation, as described in the Japanese Industrial Standards (JIS) 28113. When the light distribution of the light-emitting diode **1020** is the axially symmetrical light distribution, the reference axis **1100** serves as the axis of rotation. When the light distribution of the light-emitting diode **1020** is the axially symmetrical light distribution, the azimuth angles ϕ**1** and ϕ**2** may be set in any manner possible.

The symmetrical light distribution is light distribution having one axis of symmetry or at least one plane of symmetry, as described in JIS 28113. When the light distribution of the light-emitting diode **1020** is the symmetrical light distribution, the reference axis **1100** serves as the axis of symmetry, or a plane including the reference axis **1100** serves as the plane of symmetry. When the light distribution of the light-emitting diode **1020** is the symmetrical light distribution, the azimuth angles ϕ**1** and ϕ**2** are desirably set such that the traveling direction of the first light beam **1060** and the traveling direction of the second light beam **1061** become symmetrical about the axis of symmetry or the plane of symmetry.

The light distribution symmetrical about two planes is light distribution that includes the reference axis, and is considered symmetrical about mutually perpendicular two planes and are not rotationally symmetrical, as described in JIS 28113. When the light distribution of the light-emitting diode **1020** is the light distribution symmetrical about two planes, the azimuth angles ϕ**1** and ϕ**2** are desirably set such that the traveling direction of the first light beam **1060** and the traveling direction of the second light beam **1061** become symmetrical about the two planes.

The light distribution symmetrical about one plane is light distribution that is considered symmetrical about one plane including the reference axis, and is not rotationally symmetrical and not symmetrical about two planes, as described in JIS 28113. When the light distribution of the light-emitting diode **1020** is the light distribution symmetrical about one plane, the azimuth angles ϕ**1** and ϕ**2** are desirably set such that the traveling direction of the first light beam **1060** and the traveling direction of the second light beam **1061** become symmetrical about the one plane.

More typically, the light-emitting diode **1020** has light distribution in which the reference axis **1100** serves as the axis of symmetry or light distribution in which a plane including the reference axis **1100** serves as the plane of symmetry.

Second Embodiment

A second embodiment relates to an illumination device.

The perspective view of FIG. **5**, the top view of FIG. **6**, and the sectional view of FIG. **7** schematically illustrate an illumination device **2000** of the second embodiment. The perspective view of FIG. **8** schematically illustrates an arrangement of a light-emitting diode **2020**, photodiodes **2021**, a shielding plate **2022**, cylindrical mirrors **2023**, and an object to be illuminated **2120**.

As illustrated in FIGS. **5** to **8**, the illumination device **2000** includes the light-emitting diode **2020**, the photodiodes **2021**, the shielding plate **2022**, the cylindrical mirrors **2023**, and a housing **2024**. The shielding plate **2022** includes an inner circumferential-side plate **2040**, an outer circumferential-side plate **2041**, and communication pieces **2042**. The housing **2024** includes a cylindrical object **2060** and a lid object **2061**. The illumination device **2000** may include a structure other than these structures. The illumination device **2000** can be employed as a reflection characteristic measuring device that meets a standard of so-called 45°:0° geometry, in which illumination light illuminates a sample surface, the illumination light being incident on the sample surface from a direction making 45° with a reference axis (normal line) that passes through a center of the sample surface, and reflection light emitted from the sample surface to a direction making 0° with the reference axis is received.

The light-emitting diode **2020** emits light **2080**. Light distribution of the light-emitting diode **2020** is the same as the light distribution of the light-emitting diode **1020** of the first embodiment.

The light **2080** is formed of a first light beam **2100**, a second light beam **2101**, and a residual light beam **2102**. The first light beam **2100** is guided to an object to be illuminated **2120**, and becomes the illumination light. The second light beam **2101** is guided to the photodiodes **2021**. The residual light beam **2102** is shielded by the shielding plate **2022** and the like. A zenith angle θ**2** of a traveling direction of the second light beam **2101** is the same as a zenith angle θ**1** of a traveling direction of the first light beam **2100**. An azimuth angle ϕ**2** of the traveling direction of the second light beam **2101** is different from an azimuth angle ϕ**1** of the traveling direction of the first light beam **2100**.

The illumination device **2000** is a ring illumination device. Therefore, a spread angle of the first light beam **2100** is set to be small in a zenith angle direction, and is desirably set to 2° or less. When the spread angle of the first light beam **2100** is set to be small in the zenith angle direction, variation of an incident angle at which a light beam is actually incident becomes small with respect to an incident angle determined in a standard. The spread angle of the first light beam **2100** is set to be large in an azimuth angle direction. A spread angle of the second light beam **2101** is set to be the same as the spread angle of the first light beam **2100** in the zenith angle direction. The spread angle of the second light beam **2101** may be set to be larger than or the same as the spread angle of the first light beam **2100** in the azimuth angle direction. However, the spread angle of the second light beam **2101** is desirably set to be smaller than the spread angle of the first light beam **2100** in the azimuth angle direction. When the spread angle of the second light beam **2101** is set to be small in the azimuth angle direction and the spread angle of the first light beam **2100** is set to be large in the azimuth angle direction, a lot of light is incident on a plane to be illuminated.

The light-emitting diode **2020** may be replaced with another type of light source. For example, the light-emitting diode **2020** may be replaced with a halogen lamp, a Xenon lamp, or the like.

Each of the photodiodes **2021** detects intensity of the second light beam **2101**, and outputs an electrical signal according to the intensity of the second light beam **2101**.

The zenith angle θ**2** is the same as the zenith angle θ**1**. Therefore, the intensity of the second light beam **2101** is temporally changed, similarly to intensity of the first light beam **2100**. From the photodiodes **2021**, an index that appropriately reflects the intensity of the first light beam **2100** guided to the object to be illuminated **2120** can be obtained.

The photodiodes **2021** may be replaced with another type of photodetector. For example, the photodiodes **2021** may be replaced with photoresistors, photomultipliers, or the like. The number of the photodiodes **2021** may be increased or decreased.

Annular slits **2140** are formed in the shielding plate **2022**. Each of the annular slits **2140** is a hole extending along a circumference of a circle having a center on the reference axis **2130**, and the hole having a longer length than a width. The width is a size in a radial direction of the circle. The length is a size in a circumferential direction of the circle. The annular slits **2140** may be replaced with holes having a shape that is difficult to be called "annular slit". For example, the annular slits **2140** may be replaced with a group of a large number of circular holes arrayed in the circumferential direction of the circle.

The inner circumferential-side plate **2040** exists at an inner circumferential side of the annular slits **2140**. The outer circumferential-side plate **2041** exists at an outer circumferential side of the annular slits **2140**. The communication pieces **2042** communicate the inner circumferential-side plate **2040** and the outer circumferential-side plate **2041**. The inner circumferential-side plate **2040** and the outer circumferential-side plate **2041** become an integrated object by the communication pieces **2042**, and the shielding plate **2022** can be easily supported. The shielding plate **2022** may be replaced with a shield having a shape that is difficult to be called "shielding plate".

The annular slits **2140** and the communication pieces **2042** are alternately arrayed in the circumferential direction of the circle. The number of the annular slits **2140** may be increased/decreased. When the number of the annular slits **2140** is increased/decreased, the number of the communication pieces **2042** is increased/decreased in accordance with the number of the annular slits **2140**.

Stray light is less likely to be guided to the object to be illuminated **2120** by the shielding plate **2022**. An index that appropriately reflects the intensity of the light beam guided to the object to be illuminated **2120** can be obtained from the photodiodes **2021**.

Each of the cylindrical mirrors **2023** includes an inner circumferential reflection surface **2160**. Each of the inner circumferential reflection surfaces **2160** extends along a cylindrical surface of a cylinder including a cylindrical axis on the reference axis **2130**.

All or a part of the cylindrical mirrors **2023** may be replaced with another type of optical system. For example, all or a part of the cylindrical mirrors **2023** may be replaced with a prism. The cylindrical mirrors **2023** may be replaced with a reflection mechanism including a plurality of plane reflection surfaces. The reflection mechanism may be a plurality of plane reflection mirrors, each reflection mirror including one plane reflection surface, or may be a polyhedral mirror including a plurality of continuing plane reflection surface.

The top view of FIG. **9** schematically illustrates a polyhedral mirror.

As illustrated in FIG. **9**, the polyhedral mirror **2300** includes sixteen plane reflection surfaces **2310**. The number of the plane reflection surfaces **2310** may be increased/decreased. When a direction ground around the reference axis **2130** is a circumferential direction **2320**, and a direction approaching the reference axis **2130** is an inward direction **2322** in a radial direction, the sixteen plane reflection surfaces **2310** are dispersed and arrayed in the circumferential direction **2320** around the reference axis **2130**, and faces the inward direction **2322** in the radial direction.

The first light beam **2100** is guided to the object to be illuminated **2120** through the annular slits **2140** and the inner circumferential reflection surfaces **2160** from the light-emitting diode **2020**, and becomes illumination light. The first light beam **2100** is reflected by the inner circumferential reflection surfaces **2160**. The second light beam **2101** is directly guided to the photodiodes **2021**.

The first light beam **2100** is away from the reference axis **2130** while proceeding in the direction into which the reference axis **2130** extends, in a section from the photodiodes **2021** to the inner circumferential reflection surfaces **2160**. The first light beam **2100** approaches the reference axis **2130** while proceeding in the direction into which the reference axis **2130** extends, in a section from the inner circumferential reflection surface **2160** to the object to be illuminated **2120**, and converges on the object to be illuminated **2120**. Accordingly, the object to be illuminated **2120** is illuminated from various azimuth angles. The object to be illuminated **2120** is uniformly illuminated, and an influence of the distance from the illumination device **2000** to the object to be illuminated **2120** becomes small.

The light-emitting diode **2020**, the photodiodes **2021**, the shielding plate **2022**, and the cylindrical mirrors **2023** are supported by the housing **2024** in positions and postures that allow the first light beam **2100** and the second light beam **2101** to be guided in an aforementioned manner. The light-emitting diode **2020** is fixed to an inner surface **2180** of the lid object **2061**. The photodiodes **2021** are fixed to an inner circumferential surface **2190** of the cylindrical object **2060** through the shielding plate **2022**. The shielding plate **2022** and the cylindrical mirrors **2023** are fixed to the inner circumferential surface **2190** of the cylindrical object **2060**. One end **2200** of the cylindrical object **2060** is blocked with the lid object **2061**. The other end **2201** of the cylindrical object **2060** is released, and serves as an emission port of the illumination light. The light-emitting diode **2020**, the photodiodes **2021**, the shielding plate **2022**, and the cylindrical mirrors **2023** are housed inside the housing **2024**. The housing **2024** may be replaced with a support structure having another structure.

The light-emitting diode **2020** and the photodiodes **2021** are arranged above the shielding plate **2022**. The cylindrical mirrors **2023** and the object to be illuminated **2120** are arranged below the shielding plate **2022**. The "above" may be "above" in a vertical direction, or may not be "above" in the vertical direction. All or a part of the photodiodes **2021** may be moved below the shielding plate **2022**. For example, as illustrated in FIG. **10**, one photodiode **2021** may be moved to a gap between the adjacent cylindrical mirrors **2023**. In this case, a part of the communication pieces **2042** is omitted so that the second light beam **2101** is not shielded by the communication piece **2042**, that is, the second light beam **2101** can be guided to the photodiode **2021** through the annular slit **2140** from the light-emitting diode **2020**.

Upper surfaces **2220** of the communication pieces **2042** exist at the side of the light-emitting diode **2020**. The photodiodes **2021** are connected to the upper surfaces **2220** of the communication pieces **2042**. Accordingly, the intensity of the light beam that proceeds toward the communication pieces **2042** necessary for integrating the inner circumferential-side plate **2040** and the outer circumferential-side plate **2041**, that is, the intensity of the light beam that cannot be used as the illumination light is detected by the photodiodes **2021**. The light **2080** emitted by the light-emitting diode **2020** can be efficiently used.

Although the structure of the illumination device **2000** becomes complicated, the photodiodes **2021** may not be connected to the upper surfaces **2220** of the communication pieces **2042**. For example, it is allowed that the photodiodes **2021** are connected to an inner surface **2180** of the lid object **2061**, the mirrors are connected to the upper surfaces **2220** of the communication pieces **2042**, and the second light beam **2101** is guided to the photodiodes **2021** form the light-emitting diode **2020** through the mirrors.

Third Embodiment

A third embodiment relates to a multiangle colorimeter.

The block diagram of FIG. **11** schematically illustrates a multiangle colorimeter **3000** of the third embodiment. The block diagram of FIG. **12** schematically illustrates a control operation unit **3023**.

The multiangle colorimeter **3000** is a unidirectional illumination/multidirectional light-receiving type colorimeter. In the unidirectional illumination/multidirectional light-receiving type colorimeter, illumination is performed from one direction, reflection light from the object to be illuminated into multi directions is received, and the received reflection light is subjected to spectrometry.

The multiangle colorimeter **3000** may be replaced with another type of reflection characteristic measuring device. For example, the multiangle colorimeter **3000** may be replaced with a multidirectional illumination/unidirectional light-receiving type colorimeter, a normal colorimeter, or the like. In the multidirectional illumination/unidirectional light-receiving type colorimeter, the illumination is performed from multi directions, the reflection light from the object to be illuminated into one directional is received, and the received reflection light is subjected to spectrometry. In the normal colorimeter, illumination is performed from one direction, the reflection light from the object to be illuminated into one directional is received, and the received reflection light is subjected to spectrometry.

As illustrated in FIG. **11**, the multiangle colorimeter **3000** includes an illumination mechanism **3020**, a light-receiving mechanism **3021**, a spectrometry mechanism **3022**, and a control operation unit **3023**. The light-receiving mechanism **3021** includes a bundled fiber **3040** and a shutter **3041**. As illustrated in FIG. **12**, the control operation unit **3023** includes a spectrometry control unit **3060** and a correction unit **3061**.

The illumination mechanism **3020** includes the illumination device **1000** of the first embodiment. The illumination device **1000** of the first embodiment may be replaced with the illumination device **2000** of the second embodiment.

The light-receiving mechanism **3021** receives reflection light **3100** from an object to be illuminated **3080** with a plurality of light-receiving angles (against normal angles), and guides the reflection light **3100** to the spectrometry mechanism **3022**. The light-receiving mechanism **3021** may be omitted, and the reflection light **3100** from the object to be illuminated **3080** may be directly guided to the spectrometry mechanism **3022**. The number of light-receiving angles may be increased/decreased.

The spectrometry mechanism **3022** performs spectrometry for the guided reflection light **3100**. When the spectrometry is performed, the reflection light **3100** is dispersed by a wavelength dispersion element such as diffraction grating or a prism, change of the intensity of the light with a wavelength is detected by a sensor array or the like, and an optical spectrum is obtained. The system of the spectrometry may be changed.

The control operation unit **3023** controls the illumination mechanism **3020**, the light-receiving mechanism **3021**, and the spectrometry mechanism **3022**, and performs an operation for a measurement result. The function of the control operation unit **3023** is realized by causing a built-in computer to execute a control program. Whole or apart of the function of the control operation unit **3023** may be realized by hardware that does not execute a program. The hardware is, for example, an electronic circuit that includes an operation amplifier, a comparator, a logic circuit, and the like.

The spectrometry control unit **3060** controls the illumination mechanism **3020**, the light-receiving mechanism **3021**, and the spectrometry mechanism **3022**. The spectrometry control unit **3060** controls the illumination mechanism **3020** to illuminate the object to be illuminated **3080**. Further, the spectrometry control unit **3060** controls the shutter **3041** to open an incident port **3120** of the light-receiving angle where measurement is performed, of a plurality of incident ports **3120** of the bundled fiber **3040**, and close the residual incident ports **3120**. Further, the spectrometry control unit **3060** controls the spectrometry mechanism **3022** to cause the spectrometry mechanism **3022** to perform spectrometry, and acquires a measurement result from the spectrometry mechanism **3022**. Further, the spectrometry control unit **3060** acquires detection results of the photodiodes **1021** when the spectrometry is performed. The spectrometry control unit **3060** performs these measurement control processes for all of the light-receiving angles.

The correction unit **3061** corrects the measurement result of the spectrometry mechanism **3022**, using the detection results of the photodiode **1021**. In this correction, an influence of temporal change of the intensity of the illumination light (first light beam) is resolved. For example, the intensity of the detected second light beam is I, and a reference value of the intensity of the second light beam is I0, the intensity of the light in a result of the spectrometry is multiplied by I0/I. Accordingly, the intensity of the light in the result of the spectrometry is standardized, and the spectrometry is correctly performed.

Further, according to this correction, the spectrometry can be performed without waiting until the intensity of the illumination light is stabilized. Therefore, a time required for spectrometry can be reduced. This advantage becomes especially remarkable in a unidirectional illumination/multidirectional light-receiving type multiangle colorimeter **3000** in which the spectrometry needs to be repeated for a large number of light-receiving angles. In other words, the unidirectional illumination/multidirectional light-receiving type multiangle colorimeter **3000** that needs to repeat the spectrometry for the large number of light-receiving angles is easily subject to variation of the intensity of the illumination light. Therefore, the advantage of this correction, which reduces the influence of the intensity of the illumination light, becomes especially remarkable.

Fourth Embodiment

A fourth embodiment relates to a light-emitting diode unit in which the light-emitting diode that configures the illumination mechanism of the third embodiment is replaced.

The sectional view of FIG. **13** schematically illustrates a light-emitting diode unit **4000** of the fourth embodiment.

As illustrated in FIG. **13**, the light-emitting diode unit **4000** includes a light-emitting diode **4010**, an exterior **4011**, a substrate **4012**, a lens **4013**, and an electrode **4014**.

The light-emitting diode **4010** is mounted on an inclined region **4030** of one principal plane **4020** of the substrate **4012**. The inclined region **4030** is inclined by an angle θ with respect to a flat region **4031** of the one principal plane **4020** of the substrate **4012**. Therefore, a reference axis **4040** of the light-emitting diode **4010** extends in a direction making the angle θ with a direction into which a normal line of the flat region **4031** extends. A power feed electrode of the light-emitting diode **4010** is electrically connected with a wiring pattern exposed on the inclined region **4030**. Light distribution of the light-emitting diode **4010** is axially symmetrical light distribution where the reference axis **4040** serves as an axis of symmetry. The light-emitting diode **4010** desirably has vertical light distribution characteristics in accordance with the Lambert's cosine law.

The exterior **4011** is mounted on one principal plane **4020** of the substrate **4012**. In the exterior **4011**, a space **4050** is formed. The space **4050** is defined by an inner surface **4060** of the exterior **4011**, and is exposed to an outside of the exterior **4011** in an opening **4070** of the exterior **4011**. An end surface **4080** of the exterior **4011** along an outer circumference of the opening **4070** is fixed to a region to be fixed **4090** of the one principal plane **4020** of the substrate **4012** that surrounds the light-emitting diode **4010**. Accordingly, the opening **4070** is blocked with the one principal plane **4020** of the substrate **4012**, and the light-emitting diode **4010** is arranged in the space **4050** surrounded by the inner surface **4060** and the one principal plane **4020** of the substrate **4012**.

A hole **4100** and a hole **4101** are formed in the exterior **4011**. Each of the hole **4100** and the hole **4101** communicates the space **4050** and the outside of the exterior **4011**. The hole **4100** exists in a direction making the angle θ with the reference axis **4040** as viewed from the light-emitting diode **4010**. The hole **4101** exists in a direction making the angle θ with respect to the reference axis **4040** as viewed from the light-emitting diode **4010**. The hole **4101** exists at an opposite side to the hole **4100** with respect to the reference axis **4040**.

The exterior **4011** has a light shielding property. The exterior **4011** is desirably a resin molded body, and is more desirably integrally molded. Processing of decreasing reflectance is desirably applied to the inner surface **4060**. When the processing of decreasing the reflectance is applied to the inner surface **4060**, the stray light is suppressed.

The hole **4100** is blocked with the lens **4013**.

The electrode **4014** is provided on the other principal plane **4021** of the substrate **4012**. The electrode **4014** is electrically connected to the power feed electrode of the light-emitting diode **4010** through a wiring pattern. Accordingly, the power supplied to the electrode **4014** is fed to the power feed electrode of the light-emitting diode **4010** through the wiring pattern. When the power is fed to the power feed electrode of the light-emitting diode **4010**, the light-emitting diode **4010** emits light **4110**.

The light **4110** is formed of a first light beam **4120**, a second light beam **4121**, and a residual light beam **4122**. The first light beam **4120** is guided to the object to be illuminated through the hole **4100** and the lens **4013**, and becomes illumination light. The first light beam **4120** is condensed by the lens **4013**. The second light beam **4121** is guided to a photodiode **1021** through the hole **4101**. The residual light beam **4122** is shielded by the exterior **4011**. The first light beam **4120** proceeds to a direction making the angle θ with the reference axis **4040**. The second light beam **4121** proceeds in a direction making the angle θ with the reference axis **4040**. A traveling direction of the first light beam **4120** exists at an opposite side to the second light beam **4121** with respect to the reference axis **4040**.

When the light-emitting diode unit **4000** illustrated in FIG. **13** is employed, the second light beam **4121** may be guided through the hole **4101** to the photodiode **1021** with the optical fiber **4130**, as illustrated in FIG. **14**. In this case, an incident end **4140** of the optical fiber **4130** is connected to the hole **4101**, and the photodiode **1021** is arranged to an emission end **4141** of the optical fiber **4130**. As illustrated in FIG. **15**, a photodiode **4150** in place of the photodiode **1021** may be arranged in the hole **4101**.

Although the present invention has been illustrated and described in detail, the above description is exemplarily described and is not restrictive in all aspects. Therefore, it is understood that numerous revisions and modifications can be made without departing from the scope of the present invention.

REFERENCE SIGNS LIST

1000 Illumination device
1020 Light-emitting diode
1021 Photodiode
1022 Support structure
2000 Illumination device
2020 Light-emitting diode
2021 Photodiode
2022 Shielding plate
2023 Cylindrical mirror
2024 Housing
2040 Inner circumferential-side plate
2041 Outer circumferential-side plate
2042 Communication piece
2300 Polyhedral mirror
4010 Light-emitting diode
4011 Exterior
4150 Photodiode

The invention claimed is:

1. An illumination device comprising:

a light source configured to emit light, having a reference axis, and having light distribution in which the reference axis serves as an axis of symmetry or light distribution in which a plane including the reference axis serves as a plane of symmetry, the light including a first light beam and a second light beam, a traveling direction of the first light beam making a first angle with the reference axis, a traveling direction of the second light beam making a second angle with the reference axis, and the second angle being the same as the first angle;

a photodetector configured to detect intensity of the second light beam; and

a support structure configured to support the light source and the photodetector in positions and postures that allow the first light beam to be guided to an object to be illuminated, and the second light beam to be guided to the photodetector.

2. The illumination device according to claim **1**, further comprising:

a shield in which a hole is formed, wherein

the support structure supports the shield in a position and a posture that allow the first light beam to be guided to the object to be illuminated through the hole from the light source.

3. The illumination device according to claim **2**, further comprising:

an optical system, wherein

the shield is a shielding plate, and the hole is an annular slit, and

the support structure supports the optical system in a position and a posture that allow the first light beam to be guided to the object to be illuminated through the annular slit and the optical system from the light source.

4. The illumination device according to claim **3**, wherein

the optical system includes a cylindrical mirror including an inner circumferential reflection surface that reflects the first light beam.

5. The illumination device according to claim **3**, wherein

the optical system includes a reflection mechanism including a plurality of plane reflection surfaces that reflects the first light beam.

6. The illumination device according to claim **3**, wherein the shielding plate includes

an inner circumferential-side plate existing at an inner circumferential side of the annular slit,

an outer circumferential-side plate existing at an outer circumferential side of the annular slit, and

a communication piece that communicates the inner circumferential-side plate and the outer circumferential-side plate, and including a principal plane existing at a side of the light source, the photodetector being connected to the principal plane.

7. A reflection characteristic measuring device comprising:

the illumination device according to claim **1**;

a spectrometry mechanism configured to perform spectrometry of reflection light from the object to be illuminated; and

a correction unit configured to perform correction for a measurement result of the spectrometry mechanism, the correction resolving an influence of temporal variation of intensity of the first light beam, using a detection result of the photodetector.

8. A reflection characteristic measuring device comprising:

the illumination device according to claim **2**;

a spectrometry mechanism configured to perform spectrometry of reflection light from the object to be illuminated; and

a correction unit configured to perform correction for a measurement result of the spectrometry mechanism, the correction resolving an influence of temporal variation of intensity of the first light beam, using a detection result of the photodetector.

9. A reflection characteristic measuring device comprising:

the illumination device according to claim **3**;

a spectrometry mechanism configured to perform spectrometry of reflection light from the object to be illuminated; and

a correction unit configured to perform correction for a measurement result of the spectrometry mechanism, the correction resolving an influence of temporal variation of intensity of the first light beam, using a detection result of the photodetector.

10. The illumination device according to claim **4**, wherein the shielding plate includes

an inner circumferential-side plate existing at an inner circumferential side of the annular slit,

an outer circumferential-side plate existing at an outer circumferential side of the annular slit, and

a communication piece that communicates the inner circumferential-side plate and the outer circumferential-side plate, and including a principal plane existing at a side of the light source, the photodetector being connected to the principal plane.

11. A reflection characteristic measuring device comprising:

the illumination device according to claim **4**;

a spectrometry mechanism configured to perform spectrometry of reflection light from the object to be illuminated; and

a correction unit configured to perform correction for a measurement result of the spectrometry mechanism, the correction resolving an influence of temporal variation of intensity of the first light beam, using a detection result of the photodetector.

12. The illumination device according to claim **5**, wherein the shielding plate includes

an inner circumferential-side plate existing at an inner circumferential side of the annular slit,

an outer circumferential-side plate existing at an outer circumferential side of the annular slit, and

a communication piece that communicates the inner circumferential-side plate and the outer circumferential-side plate, and including a principal plane existing at a side of the light source, the photodetector being connected to the principal plane.

13. A reflection characteristic measuring device comprising:

the illumination device according to claim **5**;

a spectrometry mechanism configured to perform spectrometry of reflection light from the object to be illuminated; and

a correction unit configured to perform correction for a measurement result of the spectrometry mechanism, the correction resolving an influence of temporal variation of intensity of the first light beam, using a detection result of the photodetector.

14. A reflection characteristic measuring device comprising:

the illumination device according to claim **6**;

a spectrometry mechanism configured to perform spectrometry of reflection light from the object to be illuminated; and

a correction unit configured to perform correction for a measurement result of the spectrometry mechanism, the correction resolving an influence of temporal variation of intensity of the first light beam, using a detection result of the photodetector.

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